Journal of Biotechnology and Biodiversity, April 2010; 1(1): 14-19
ISSN: 2087-0183

RESEARCH

Solar radiation in agro-forestry system

Djoko Purnomo [a*], Syukur Makmur Sitompul [b], Mth. Sri Budiastuti[a]
[a]*Department of Agrotechnology, Faculty of Agriculture, University of Sebelas Maret, Jl. Ir. Sutami 36 A, Surakarta 57126, Indonesia*
[b]*Department of Agronomy, Faculty of Agriculture, University of Brawijaya, Jl. Veteran, Malang 65145, Indonesia*

Received: 13 November 2009
Accepted: 21 December 2009

Abstract
Quantitative information about solar radiation in agro-forestry system in Indonesia is relatively limited. To study the amount of solar radiation below forest trees stand, a survey based research was conducted from October 2002 to February 2003 in Central of Java, Indonesia. The locations of the survey were chosen based on the kinds of trees and forests. They were Purwodadi (teak, mahogany and sonokeling production forest), Karanganyar - Purworejo (pines production forest), and Klaten (semolina and yucca as conservation forest). The decrease in the Relative's Irradiation Fraction (RIF) under the trees was found related to the increased of the tree aging, adjusted to the exponential decrease model (RIF=1.25e $^{-0.18\ X}$). The RIF under tree canopy was clearly explained by diameter on the breast height diameter of trunk (DBH) divided by the half of tree row spacing (2D/(X + Y) therefore the RIF was formulated as e$^{-0.2829\ (2D/(X+Y)}$.

Key words: Radiation, Agroforestry

INTRODUCTION

Agro-forestry system has been practiced widely by farmers in several forest areas in Indonesia. *Perhutani* (Indonesian state forest authority) has social forestry program (which includes of husbandry, fishery, and multiple cropping in forest land areas) for minimizing forest disturbance. In Central of Java Indonesia in 1986 the program started with 52.00 ha then increased to 1,396.75 ha in 1993 [(1)] and in 2001 it reached 20,124.00 ha [(2)]. The high increasing rate of social forestry area shows that the necessity of agricultural land in common area is unavailable since the high rate of change in function from common agricultural land to others. In multiple cropping systems there will be competitions for obtaining water, mineral, and solar radiation between crops and trees. The competition occurs if the resource is limited. To avoid the competition of water and mineral is generally done by coupled planting time with rainy season and fertilization. On the other hand, the solar radiation adjustment for crop mainly in low level because of tree shading is still lack of information. So it is very important to find out the quantitative solar radiation information among the canopy trees.

Solar radiation is difference from the other growth factors because it is constant and its only source is the sun. In agro-forestry system the available light for crop is the sun light which penetrates the tree canopy so the tree canopy character is a very important factor. The canopy character is canopy density which is determined by the height of tree, diameter of trunk, height and wide of canopy, and trees population (reflected by tree spacing between and in row). The light penetrating the canopy could be varies in time since there is a

Correspondences Author:
*Djoko Purnomo
Department of Agrotechnology, Faculty of Agriculture,
Sebelas Maret University, Jl. Ir. Sutami 36 A, Surakarta 57126
Telephone / Fax: (0271) 632451/ (0271) 632451
E-mail: djkprnm@yahoo.com

movement of canopy by the tree caused by outer factor like the wind [3]. Radiation fraction between the tree rows is high in the middle row and it reduce to the tree rows (under the trunk) [4]. The number of infra red light in agro-forestry system is presumably like in multiple cropping system so it is higher comparing with that of the mono cropping system [5, 6].

A complete development model for estimating the available light for crop is needed for calculating the potential of agro-forestry system. The previous models in tree-crop interaction [7, 8] have not discussed the light factor yet. The previous research generally conducted in semi natural agro-forestry for such hedgerow-intercropping system [8-11]. The data analyzed from several publications ([12-13]) shows the variety in the tree-crop interaction. The negative interaction occurs in casuarinas + maize system and gliricidia + maize, and positive in leucaena + maize (Sitompul, unpublished).

The present research was conducted to find out the quantitative radiation penetration in several tree forest canopies, the quantitative radiation penetration related to the tree age and the model of radiation penetration related to canopy character and tree spacing. The quantitative information obtained was expected to determine the tree management scenario suitable with the kinds of crop that will be cultivated among the tree population.

MATERIALS AND METHODS

A survey based research was conducted in Central of Java Indonesia forest area on October 2002 until February 2003. The survey sites were chosen based on their kinds of forest and forest tree, they were: Purwodadi as teak (*Tectona grandis*), sonokeling (*Dalbergia latifolia*) and mahogany (*Swietenia mahogani*) production forest, Karanganyar and Purworejo as pines (*Pinus merkusii*) production forest, and Klaten as conservation forest with semolina (*Gmelina arborea*) and yucca (*Eucalyptus sp.*) trees.

The data were observed on three stages of tree ages: juvenile, develop, and adult (if available) and the measurement were conducted on a group of 10 trees. The data observed were height of tree (measured by Haga meter), height and wide of canopy, diameter of trunk on breast height (DBH, about 1.3 m above the soil surface), number of branches, and tree spacing between and in of the tree rows. Solar radiation penetration was measured by Dx 100 Lux meter type (the results was then calibrated by LI-COR 191SB Light meter type for obtaining μmol m^{-2} s^{-1} unit) at point 0.0, 0.2, 0.5, 1.0 and 3.0 m distance from the trunk toward the middle row, respectively. The light measurement was conducted below the pruning tree (low part of canopy branches as big as 50 % canopy height) and the open space, and it points was conducted simultaneously.

RESULTS AND DISCUSSION

The penetration level of solar radiation was calculated in relatives irradiance fraction (RIF) by compared the solar radiation level below the trees and the open space (in %). The RIF varies among the kinds of tree on the different growth levels (different age stage). The variation was related to the canopy density which expressed in canopy biomass unit (trunk, branch, and leaf) per unit space of radiation transmission. The canopy biomass unit was reflected by canopy architecture: height and wide of canopy, height of tree, and number of branches.

The changes of teak canopy architecture by the tree growth and development (since the increasing of age) had positive correlation quotient ($r > 0.0$) with the height and wide of canopy, number of branches, and DBH (r values were 0.81, 0.81, 0.55 and 0.91, respectively). The present condition determines the RIF pattern from the tree row toward to the middle of row. Near the tree trunk the correlation quotient of RIF and the height and wide of canopy, number of branches, and DBH was negative (-0.60, -0.69, -0.75 and -0.63, respectively). At the point of 0.2 m distance from the row toward the middle of row the r values of RIF with those components were -0.5, -0.59, -0.73 and -0.51, and at the point more than 0.2 m distance toward the row the r value was less than 0.5. The result was expected because the canopy density near the middle of the row was smaller than near the trunk. If the age of the tree increases, the RIF decreases either near the trunk or on the middle of row. Penetration of solar radiation among the teak tree spacing 6 X 6 m on 8 years old was high enough for crop.

On the other hand, in pines the high correlation quotient (r = 0.94) between increasing tree age and canopy density components was on DBH only. Correlation quotient between the tree age and the other components was less than 0.40. Correlation quotient between the tree age and the RIF varies among the point of observation 0.2, 0.5, 1.0, and 1.5 m from the trunk were -0.67, -0.63, -0.53, -0.40 and -0.41, respectively. Among the canopy components only DBH had r value more than -0.4 (-0.71, -0.65, -0.60, -0.48 and -0.49), at the point of observation 0.2, 0.5, 1.0, and 1.5 m from the trunk toward the middle of row, respectively. If the age of pines increases, the RIF decreases either near the trunk or on the middle of row. Penetration of solar radiation among the pines tree spacing 3 X 3 m on 8 years old was high enough for crop.

Mahogany on the site observed was just 6 years old with 6 X 6 m spacing. The high correlation quotient was mainly between wide of canopy and RIF (r = 0.77) at the point observation of 3.0 m (middle of row) from near the trunk, also between the number of branches and RIF at the point observation of 1.0 m from near the trunk (r = 0.56). Semolina and Yucca tree (all of them on 8 years old) were as conservation tree, so they were planted at random and penetrate the solar radiation about 90 % and 70 % respectively.

The increasing of tree aging followed by the tree development was reflected in increasing of canopy density impact to the RIF, decrease from < 90 % (on one year old) to < 5 % (on 20 years old) (Figure 1A). The decreasing of RIF was related to the increasing tree aging following the exponential model, RIF = $1.2461e^{-0.1824U}$; R^2 = 0.8743 (n = 60). The changes of radiation transmission level caused by the changes of tree (teak, pines, and mahogany) aging can be covered by the model. This means that the decreasing of RIF were inconsistent with the increasing of tree aging, due to the other factors influence the radiation transmission through the tree canopy which did not depend on tree aging. The general interpretation of exponential model is that the

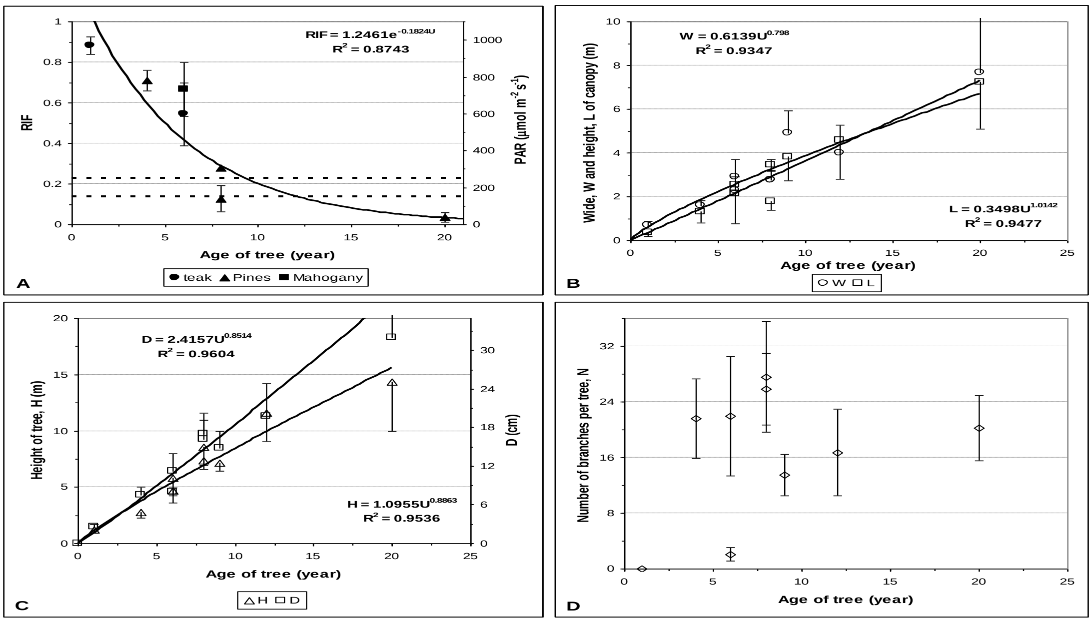


Figure 1. The relationship between the RIF below tree canopy with the tree age (Figure A), and relation of canopy wide (W), canopy height (L), tree height (H) and branches number (N) with tree age (Figure B, C, and D), respectively. The vertical bar is standard deviation. Every data in the figure was the average of 10 trees.

interpretation of exponential model is that the decrease of radiation transmission (I) with the increasing of tree aging (t) depend on incoming radiation ($\delta I/\delta t = kI$ and $I = I_0e^{-kt}$). In other word, radiation transmission level through the tree canopy does not depend on the kinds and age of tree only, but also determined by radiation level above the tree canopy too.

Interpretation of exponential model as mentioned above can be used if the tree aging represents the canopy density. There was an integration of wide of canopy, height of canopy, number of branches compared with tree spacing. The development of canopy wide (W), canopy height (L), height of tree (H), and DBH (D) was closely linear with the increase of tree aging (Figure 1B and C). On the other hand, the development of branches varies in the kinds of tree but there was no significant or clear correlation with tree aging (Figure 1D). It means that the tree aging could not represent the canopy density and the number of branches is unimportant component of canopy density.

The trunk diameter (D) which was related to the height of tree (H), canopy wide (W), and canopy height (L), had a good relation with the number of branches (N) (Figure 2B). The relation was better than the relation of branches number and height of tree. There was also a close relationship between the canopy wide and the height of canopy like the trunk diameter. So, the trunk diameter was better than tree aging for explaining the difference of tree kinds in the same age. Trunk diameter (DBH) is also widely used in tree biomass (above soil surface) taxation.

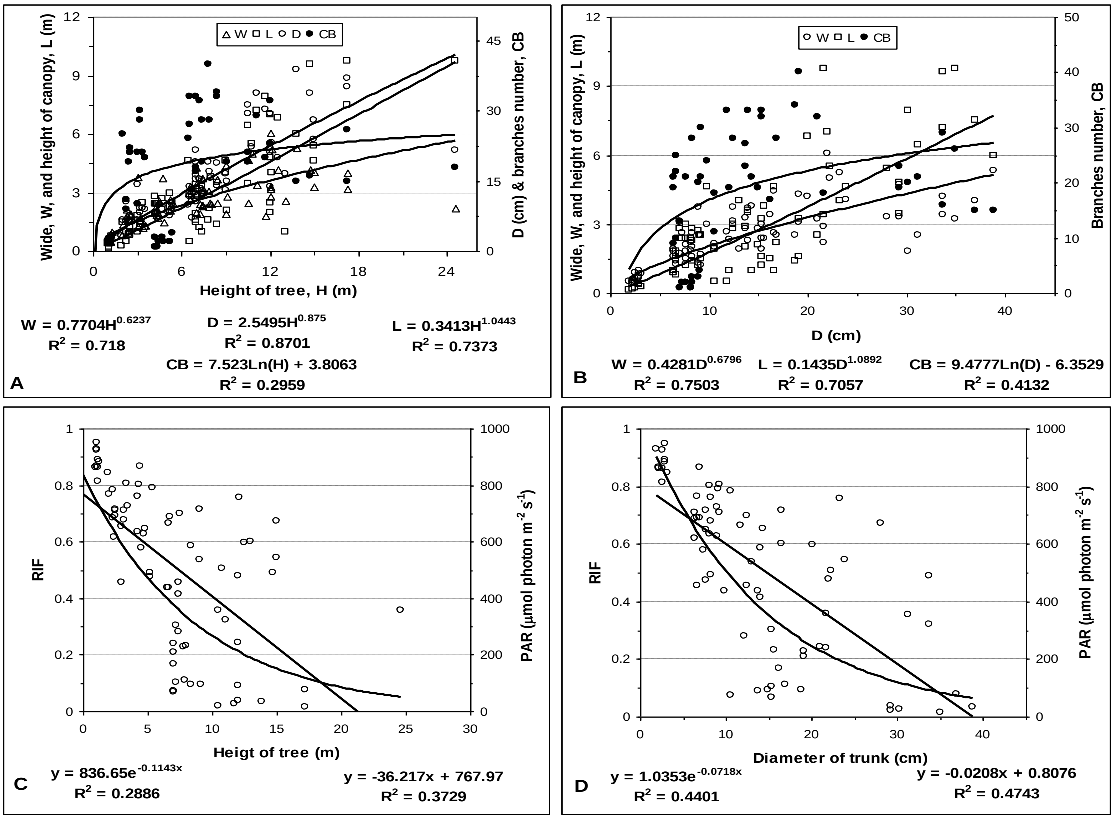
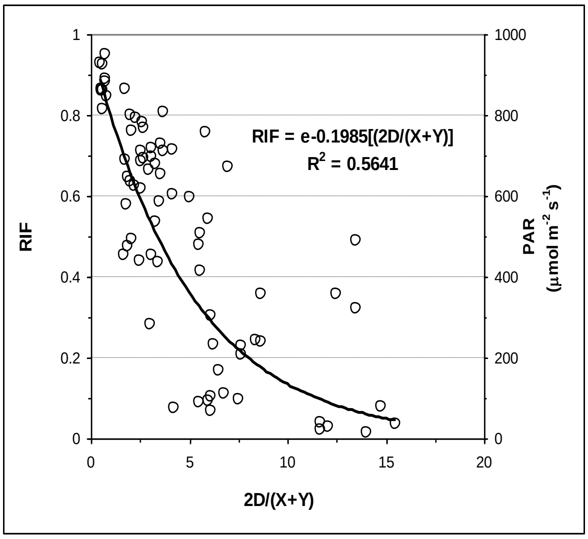


Figure 2. The relationship between canopy wide (W), height of canopy (L), breast height trunk diameter (D) and branches number (N) with the height of tree (H) (A), relation of W, L, W X L, and N with D (B), relation of RIF & PAR with H (C), and the relation of RIF & PAR with D (D). Each of the data in the figure represents the individual tree. Vertical bar is standard deviation.

For the radiation below the tree canopy which was represented by the RIF showed that the relation between RIF and D was better than RIF and H. The difference of tree spacing among trees community then was corrected by divided the D with the average of tree spacing. So, the RIF was function of 2D/(X + Y); X was the tree spacing and Y was the row spacing. As result by this approach, the relation between RIF and 2D/(X + Y) (Figure 3 A) was better than between the RIF and the other growth parameters. The radiation transmission level below the tree canopy was clearly explain by 2D/(X + Y) mainly if the RIF model developed just for the average RIF taxation in the tree population (Figure 3 B).

As the conclusion, the models RIF = $e^{-0.2829\ 2D/(X+Y)}$ and RIF = $1.2461e^{-0.1824U}$ could be used for calculating the RIF or the number of PAR penetrates the tree canopy at the certain spacing and age. Managing the tree spacing related with the age of tree and the canopy pruning could be used for agroforestry planing. Pruning of the lower part canopy branches (50 % height of canopy) was increased the RIF by 90 % and 80 %, on teak and pines, respectively. Calculation of the RIF and PAR below the teak canopy (pruning and no pruning) by using the model of relation between the age and tree diameter, PAR with age and diameter with height of tree was presented in Table 1. Height of tree is the pursuer of pruning conduction so the technological innovation has to be developed.



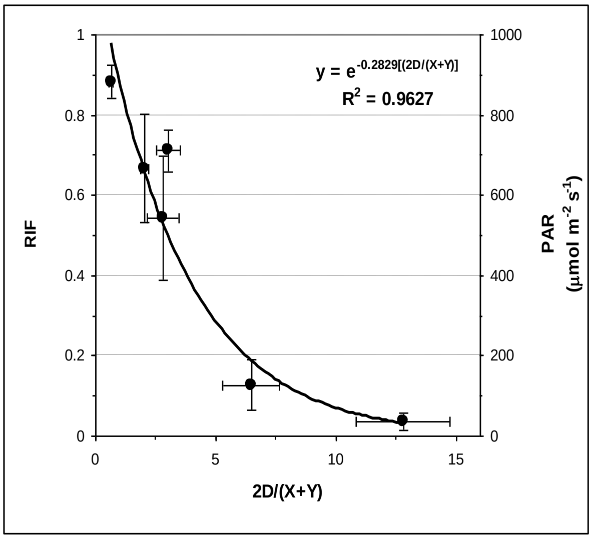


Figure 3. The relationship between RIF and PAR with 2D/[(X + Y)] for individual tree (left) and for the average of tree (right). Vertical and horizontal bar is standard deviation of the RIF data. X and Y is tree spacing.

Table 1. The change of DBH, RIF, PAR and tree height of teak at several ages and tree spacing

Age (year)	DBH (cm)	RIF 2x6	PAR (µmol m^{-2} s^{-1}) at tree spacing (m)						Height of tree (m)
			2X6	Pruning	4x6	Pruning	8x6	Pruning	
5	9.51	0.51	510	709	584	768	639	830	7
6	11.11	0.46	456	658	533	729	592	805	8
7	12.66	0.41	408	609	488	689	550	780	10
8	14.19	0.37	367	562	448	651	512	753	11
9	15.69	0.33	330	518	412	613	477	727	12
10	17.16	0.30	297	476	379	576	445	700	13
11	18.61	0.27	268	438	349	541	416	673	14
12	20.04	0.24	242	402	322	508	389	647	15
13	21.45	0.22	219	369	297	476	364	622	16
14	22.85	0.20	199	338	275	446	341	597	18
15	24.23	0.18	180	310	254	418	319	573	19

DBH: breast height diameter (about 1.3 m above soil surface). Pruning: low part (50 % canopy height) of canopy branches was pruned. PAR (photosynthetic active radiation) was calculated based on the average PAR on the open space as big as 1000 µmol m^{-2} s^{-1}. RIF is relative irradiation fraction.

REFERENCES

1. Faperta UNS. 1996. Studi pengembangan model sistem agroforestri pada perhutanan sosial: studi kasus di unit I Perum Perhutani Jawa Tengah. Laporan Penelitian. Badan Penelitian dan Pengembangan Dep. Kehutanan RI-Fakultas Pertanian UNS.
2. Perhutani Unit I. 2001. Buku saku statistik tahun 1997-2001. Semarang.
3. Braconnier, S. 1998. Maize-Coconut intercropping: effects of shade and root competition on maize growth and yield. Agronomie 18: 373-382.
4. Sitompul, S. M., Hairiah, K., Cadisch, G., van Noordwijk, M. 2000. Dynamics of density fractions of macro-organic matter after forest conversion to sugarcane and woodlots. Accounted for in a modified century model. Netherlands Journal of Agricultural Science 48: 61-73.
5. Board, J. 2000. Light interception efficiency and light quality affect yield compensation of soybean at low plant population. Crop Science 40: 1285-1295.
6. Cober, E. R., Voldeng, H. D. 2001. Low r:fr light quality delays flowering of *E7E7* soybeans lines. Crop Science. 41: 1823-1826.
7. Ong, C. K., Huxley, P. 1996. Tree-Crop interactions. CAB International. University Press. Cambridge. Wallingford/Nairobi.
8. Hairiah, K., Utami, S. R., Suprayogo, D., Widianto, Sitompul, S.M., Sunaryo, et al. 2000. Agroforestry on acid soils in the humid tropics: managing tree-soil-crop interactions. International Centre for Research in Agroforestry. pp: 38.
9. Sitompul, S. M., Syekhfani, van der Heide. 1992. Yield of maize and soybean in a hedgerow intercropping system. Agrivita 15: 69-75.
10. Sitompul, S. M. 1994. Budidaya lorong untuk sistem pertanian terlanjutkan pada lahan kering beriklim basah. laporan hasil penelitian. Proyek Pembangunan Penelitian Pertanian Nasional. Badan Penelitian (P4N/ARM) dan Pengembangan Pertanian.
11. van Noordwijk, M., Hairiah, K., Sitompul, S. M., Syekhfani, M. S. 1992. Rotational Hedgerow Intercropping + Peltophorum pterocarpum = New hope for weed-infested soils. Agroforestry Today. October-December: 4-6.
12. Getahun, A., Jama, B. 1989. Alley cropping in the coastal area of Kenya. In: Alley farming in the humid and subhumid tropics. Kang, B. T., Reynolds, L. (eds). International Development Research Centre. Ottawa. Canada. pp: 163-170.
13. Kang, B. T., van der Kruijs, A. C. B. M., Couper, D. C. 1986. Alley cropping for food crop production in the humid and subhumid tropics. In: Alley farming in the humid and subhumid tropics. Kang, B.T., Reynolds, L. (eds). International Development Research Centre. Ottawa. Canada. pp:16-26